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R. J. H. Beverton

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1. Lecture. Life History and Recruitment Fluctuations of Fish

by R.J.H. Beverton

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Dr. R.J.H. Beverton who is a U.K. scholar in marine stock science came to Japan for a first visit on April 17, 1982. On this occasion, he kindly accepted our request for a symposium sponsored by the Society for Research in Fisheries and Oceans. The symposium lasted from 2:00 PM till 5:00 PM on April 22. It was held in the auditorium of the Marine Research Center of the Tokyo University and attended with great interest by about 40 persons. Mr. Tanaka summarized the lecture, using the audio records of the day. Mr. Tanaka is solely responsible for any possible error concerning these records. Dr. Beverton showed numerous diagrams. These are not given here. We asked two young assistant researchers having attended the symposium to write down for us their impressions regarding these lectures.

(Masaichi TANAKA - Marine Research Center, Tokyo University)

1. Lecture Life history and recruitment fluctuations of fish

Today I would like to explain my views about the way in which studies in stocks developed during the past 10, 20 years. As I left the Fisheries Research Center of Lowestoft in 1965, I have been unable to participate directly in studies on stocks. I have however therefore been able to observe the development from the outside. During that time, research in stocks advanced remarkably and abundant data have been obtained on the ways in which catches and natural actions affect the stocks. Twenty years ago, the mechanism regulating naturally the densities were discussed only in a theoretical fashion. At the present time, this mechanism has been corroborated by numerous data. From now on, we will solicit study results obtained by the many researchers of all countries in the northeast Atlantic and in the North Sea areas.

Plaice (Pleuronectes platessa)

The plaice of the North Sea is an important fisheries resource and has been studied for a long time. The spawning grounds, the nursery grounds of the fry and larvae as well as the distribution of the adult fish is well known. During the January-March winter period, spawning takes place on the North Sea banks after which the fry floats around for about two months to gather in the coastal areas in May, June for a benthonic mode of life. Fish at this stage are called postage stamp fish. In the most coastal areas of a depth of 1 m or less, the density is remarkably high. In October, November the fish move to the open sea but come back to the coasts in the following year. The density is

however lower than during the first year. The homing habit of the parent fish moving to the spawning grounds is marked, that is, it reaches up to 95%.

The reason why we explained in detail the life history of the plaice while talking about the mechanism adjusting the individual shoals is that it is indispensable to know perfectly the life history of the fish in order to explain the manner in which the stocks have been able to be present in the environment throughout long successions of generations.

The plaice stocks were vigorously exploited prior to the second world war but fishing was stopped in the 1940-45 period because of the war, and one saw a remarkable recovery of the stocks. During the 1945-1950 period the stocks declined again but have thereafter remained stable, and are now kept within definite limits. One may say that there has been a natural adjustment.

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The volume of recruitment to the stocks is indicated in volume of two-year old fish counted by the virtual population method. The annual variations are small and for the greatest part contained within ±30%. The 1963 year class reached 3-4 times the average level. We will touch on this later. If we compare the volume of recruitment and the parent fish stocks, we see that there is no mutual relationship. The volume of the stocks was large in 1946. Yet, the size of the year class groups was average. The 1957-59 year classes were relatively large but the parent fish were few during these same years. The 1963 parent fish volume which produced a banner year class were of an average level too. Thus the

stability of the recruitment volume regardless of the volume of parent fish is due to some natural regulatory action. We do not know however at what development stage, where and in which manner the action proceeds.

As Hjort demonstrated, fish suffer great losses at the initial period of their life history. It is therefore possible that the adjustments are carried out at this stage. We devised a high-speed plankton net with a 80 cm opening and were able to survey for 4 days the entire spawning grounds. In January-April 1962, we repeated our surveys every week for five days from Monday to Friday and obtained a mass of information. Since in January 1963, one registered abnormally low temperatures supposed to appear only 1 time in 100 years, we carried out the surveys again just as in the previous year.

By comparing the distribution of the February-April larvae and fry p. 88
over the two years, we discovered the following. In 1962, the water temperature at the spawning grounds was 6-7°C and represented that of an average year. After 60 days following hatching, the larvae and fry ended their floating life in the central North Sea and changed to a benthonic mode of life. As a result, it became necessary to migrate to the bottom layer of the nursery grounds along the coasts which in some cases meant a trip of 100 km. Meanwhile, the growth was remarkably delayed in 1963 because of the low temperatures. Even in April, one saw nothing but larvae at the initial development stage, and the distribution of the larvae was markedly widened during the floating life period. It widened beyond the limits of the surveyed sea area. It seems that in

this year the distribution widened as far as the nursery grounds at the floating life period, and that the survival rate was high.

A comparison of the 5 year-classes for 1962, 63 and 1968, 69, 71 reveals that the survival curves of the 3-year classes for 1962, 68 and 71 overlap well. Meanwhile, as the distribution widened beyond the survey area in 1963, we were able to keep track for 80 days only. However, the density was extremely high and reached up to 100 times the average annual level. The two-year old fish (recruitment volume) of the 1963 year class did not exceed 4 times the annual average. The volume of spawning in 1969 was average but survival was good and the volume of floating larvae represented about 100 times the annual average after about 120 days. The level of abundance for this year class represented the average level at recruitment time.

The above results demonstrate that the regulating action is still insufficient at the floating life period, and that the control was performed later. In point of fact, the density at the floating period is 1 individual per 1 m^3 at the highest, and it does not appear that the density effect works strongly. Meanwhile, the fry distribution in the coastal waters shows an extremely high distribution density. The nursery grounds are along the coasts of Denmark and of The Netherlands. No survey is possible off England. There are questions about the period of displacement toward the nursery grounds following the switch to the benthonic mode of life. Investigations are however difficult and no survival curves were obtained after more than 150 days.

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The young scientist who replaced me at the Lowestoft research center studied the May-October survival of the fry at the various coastal sites of the North Sea. When plotting the natural death coefficient against the density, it was seen that the death coefficient increased together with the density. If we assume thus that a relatively high death coefficient works throughout a half year, it is possible to explain that large differences in the degree of abundance at the larval period are completely narrowed at the recruitment time. It seems that the density control action is in effect at the stage of fry living along the coasts.

If one believes that the mechanism of density control consists in the competition for food, then the same should appear to affect the growth. Observations of 1965 fry body length compositions made at the Aberdeen fisheries research center show that the types are uniform when the fry reach the coast in May, and that there is little dispersion. However, the distribution width increases as the seasons go by. There is much dispersion between the fall and the end of the year. These facts suggest a strong competition between the individuals. It would seem that as only the well developing individuals survive, density control is realized.

One would like to use plaice to conduct tests regarding the differences in feeding based on individual sizes. As such tests were difficult, we used Betta splendens fry, fed them Daphnia nauplius in a determined density and watched the numbers of catch. If one plots the feeding rate against the body length (mm) on dual logarithmic plotting paper, one observes a rectilinear tendency. The gradient was 5.3. This

means that feeding is proportional to $L^{5.3}$ with respect to the body length L. A small increase in body length represents a marked increase in the feeding rate. The same phenomenon is believed to occur in the case of plaice.

The above research is not yet systematic enough but one should realize how difficult, time-consuming and expensive marine studies are. We established an hypothesis, confirmed it, and by advancing to the next stage we are coming closer to the real facts. Our hypothesis was that the volume of plaice recruitment is controlled within a width showing little variation as a result of a natural control action brought about by the life history of dense gathering in the coastal areas. The next question is whether the hypothesis may also be applied to the other species. We will hereafter compare with regard to several fish species of the North Sea, the relationships between the life histories of the respective species and the variations in their recruitment volumes.

Sole (Solea solea)

The life history of the sole is similar to that of the plaice. The difference is that the spawning grounds and the nursery grounds are both along the coast. The relationship between stocks and recruitment volume resembles the same relationship with regard to plaice and the variation width reaches 4-5 times the stock volumes. Yet, the recruitment volume was contained in a ±50% range except for the years 1958, 1963. The year 1963 had a great cold wave and the year class of plaice was abundant. As for 1958, a relatively large year class was obtained with plaice in

1958-1960. In this year, the current was strong in the Dover straits and large quantities of Atlantic water flowed into the North Sea spawning grounds.

Whereas the spawning grounds of plaice are concentrated in specific offshore areas, those of sole are scattered in the various sites along the coasts and there are differences in the effect exercised by the regional conditions. The variation width of the recruitment volume is larger than for plaice but well controlled.

Haddock (Melanogrammus aeglefinus)

The haddock fish species stands in sharp contrast with plaice and sole. Both the spawning and nursery grounds are in the northern part of the North Sea. The floating larvae and fry are distributed in the same sea area. The distribution is extremely wide, extending 350 km to the north and south, and 150 km in the east-west direction. The switch to the benthonic mode of life takes also place in this area. The marine research center of Aberdeen has pursued the study of this fish species for several decades. A first look at the correlation between the volume of stock and of recruitment based on the obtained data reveals that the variations in recruitment volume are extremely large. The variation width reaches up to 1,000 times. The haddock larvae and fry are distributed over the entire North Sea. They do not congregate in the narrow coastal areas. It seems therefore that there is practically no controlling action.

Herring (Clupea harengus)

As there are several separate herring stocks, the situation is complex. Basically both the spawning grounds and the nursery grounds are along the coasts. Yet, as herring are swimming fish they have no benthonic life like plaice. They do not congregate either in shallow sea areas. One knows that they live first for 1-2 years in the coastal areas. The correlation between stock and recruitment volume shows that the width of variation in stock and recruitment volume are kept within a relatively narrow range except for a few exceptions of double or triple amounts. We see that the control action takes place while the fish are in the coastal development grounds.

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Stock - recruitment volume correlation

In order to prove the above hypothesis about the life history and recruitment volume, one should conduct similar studies about numerous other fish species. In Japan, there is the Kuroshio current so that the pelagic conditions are more complex than in the North Sea. One might however see similar things. To change the topic, I will now consider the effects of fishing.

If in the stock regeneration relationship the volume of recruitment is stable without any decrease, then according to the theory of catch volume per recruitment volume, it is not possible to diminish the stocks to the point where there would occur a decline in recruitment volume. Yet, the actual fact that occurred in the North Sea is the destruction of

the herring stock even though there had been times of peak 750,000-tonne catches. In 1970-75 the stocks as well as the recruitment volumes fell sharply, and 1975 brought annihilation. As a result, fishing was forbidden for 5 years from 1975 to 1980. Fortunately, the stocks recovered and even a catch of 100,000 tonnes was authorized. The above facts show that when the stocks decline below a determined level, they reach rapidly annihilation. Since 1903, the amounts of catch were extremely stable, with the exception of low production during the war years. Declines in the amount of catch were noted from 1965. If we consider the amount of catch per effort, we see that the stocks kept declining after the war.

An important question in purse seine fishing provided with sonar is to know what changes occurred in the fishing power at the time when stocks of swimming fish such as herring declined. If we consider the fishing coefficient F of 1946-75, we see that from around 1967 when the stocks were declining it increased and reached up to about 1.5. If we convert to catch rate, we obtain 80%. The reason is that because of progress in catching technology, catching had with the help of sonars become quite effective. The destruction of the Norway herring stocks was still more severe.

At the time when F was about 0.5 the stocks were stable. However, as the stocks declined over the recent years, F rose above 1.0 in the end. Recently a researcher at the Lowestoft research center made an estimation of the relationship between the catch coefficient F and the volume of catch incorporating the correlation between stocks and

recruitment volume. Regarding the volume of catch per volume of recruitment, the volume of catch does not decline even though fishing is intensified. However, if we consider the stock-recruitment volume relationship, we see a change in the situation. With F=0.5, one may expect a high balanced fishing volume. If F exceeds 0.7 the volume of catch drops suddenly and if F=0.9, then 0 is finally reached. Actually, as F exceeded 1.0, it is quite normal that the North Sea herring stocks were destroyed. Fortunately fishing was forbidden and the stocks turned around toward recovery even though they were on the brink of total destruction.

Twenty years earlier, theoretical computations based on models were made but one did not believe that such things would actually happen. Sadly enough, the theoretical forecasts were proven correct. The sole stocks have over the recent years been affected by vigorous fishing, and the stocks are conspicuously declining. Yet, the recruitment volumes of the1974-76 year classes were stable and no declining tendency was shown. If the stocks are allowed to decrease further the volume of recruitment too might decline. So, the scientists are of the opinion that the stocks may not drop beyond the present level. What we see however is that the volume of recruitment is actually stable and one fears that this may induce fisheries operators and policy makers into erroneously believing that there is no risk of decline in recruitment volume. We may in fact be standing on the brink of a very dangerous situation.

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